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USAARL Report No. 77-4

MEASUREMENT OF AVIATOR VISUAL PERFORMANCE AND WORKLOAD DURING HELICOPTER OPERATIONS

By

Ronald R. Simmons

Kent A. Kimball

Jamie J. Diaz

December 1976

Final Report

U.S. ARMY AEROMEDICAL RESEARCH LABORATORY

Fort Rucker, Alabama 36362

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report was initiated to review the techniques and modifications developed by the U.S. Army Aeromedical Research Laboratory for assessing visual performance/workload of pilots during helicopter operations. Although the corneal reflection technique for gathering eye movement data is not new, innovative modifications had to be developed to permit accurate data collection in this flight environment. This study reports on these techniques, modifications, and applications.

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SUMMARY

This report was initiated to review the techniques and modifications developed by the U.S. Army Aeromedical Research Laboratory for assessing visual performance/workload of pilots during helicopter operations. Although the corneal reflection technique for gathering eye movement data is not new, innovative modifications had to be developed to permit accurate data collection in this flight environment. This study reports on these techniques, modifications, and applications.

ROBERT W. BAILEY
Colonel, MSC
Commanding

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INTRODUCTION

Evolving from the Army's modern air mobility concept, the helicopter has become a strategic element of the tactical structure. The helicopter is no longer utilized exclusively for air transportation as its fixed wing predecessors were, but is presently also a platform for armament, a vehicle for reconnaissance, and an unsurpassed mode for rapid evacuation of wounded personnel from the combat environment. As the mission of this vehicle becomes more complex, so do the tasks of the pilots who fly them. Pilots no longer simply manipulate the aircraft, but now share this duty with other responsibilities dictated by mission requirements. Little is known about aviator visual and motor workload during helicopter flight under varying mission profiles, and even less can be predicted about the available free time which a pilot can utilize for secondary mission tasks.

The pilot's ability to manipulate his aircraft in a tactical setting is directly related to the inputs or cues he receives from the flight environment. Of those perceptual inputs required to fly the aircraft, visual cues are considered vital. Processing and integrating these cues allow the pilot to detect the aircraft's relative stability, ground reference, and response to his control inputs. During flights conducted under instrument meteorological conditions (IMC), the lack of cues from the environment outside the aircraft requires the pilot to obtain the necessary visual information from instrument displays. As a consequence, there exists the need, independent of visual conditions, to determine what cues are required to achieve maximum pilot efficiency for safe mission accomplishment.

A great variety of apparatus and techniques have been developed for the study of visual performance/workload.[1,2,3] However, the state-of-the-art in eye movement recording instrumentation is still in its infancy. One of the earliest devices was a smoked-drum Kymograph attached to the sclera of the eyeball via fine wire and barbed hooks. During the 1930's the electro-oculography (EOG) technique was developed which utilized electrodes placed around the eyes on the facial structure to monitor differential voltages as the eyeball was rotated.[4]

The earliest documented technique for measuring the visual performance of pilots was to simply record pictures of the human operator's face while he scanned the instruments.[5] Improvements of this method were accomplished by arranging mirrors on the instrument panel and

photographing the total arrangement. Documentation of eye movement was obtained by means of a camera mounted behind the pilot. During analysis, a photo interpreter scanned the film to determine which mirror reflected the eye of the pilot at various times during the flight.[6]

This technique was further refined by Mackworth.[7] His approach was to mount a light weight moving picture camera beside the operator's head along with a series of mirrors which reflected a dot representing the eye's motion. This dot was superimposed on photographs of the scene directly in front of the head's centerline. More recently this same "corneal reflection" technique has been utilized by the U. S. Army Aeromedical Research Laboratory in the study of Army pilot visual performance during helicopter flight.[8,9]

Because of the smooth spherical front surface of the cornea, an incident beam of light can be partially reflected forming a bright spot or "highlight" on the cornea. The angle of the reflected light depends upon the angle between the incident light ray and a plane tangent to the reflecting surface. Since the cornea forms an eccentric bulge on the nearly spherical eyeball, the angle of this tangential plane on the cornea at any one point changes as the eye rotates about its center during eye movement. As a result, the position of the highlight follows the direction of movement of the cornea. The reflected beam is easily photographed on film. By mounting a camera lens on a subject's head slightly above and between his eyes, the subject's normal visual field can be recorded, and the highlight can be superimposed on the scene to give a constant eye reference in the subject's field of view. By recording both the visual field and the eye's highlight, the areas of visual concentration and the percent of time for eye stabilization during any flight maneuver can be recorded.

Past research has demonstrated two major advantages of the corneal reflection technique for studying eye movement. First, the method is convenient for large scale testing of subjects in that it requires minimal training. Second, these studies have reported no significant interference with normal eye movement.[10,11]

The purpose of this report is to provide a description of the modifications which have been made to the eyemark recording apparatus to improve its data acquisition efficiency for helicopter flight and to delineate the methodology which has been developed for the field application of the device subsequent to these modifications.

This method has been instrumental in obtaining baseline information on pilot visual workload during various helicopter operations, including instrument flight (IFR), visual flight (VFR), and terrain flight. The application of this information to the development of more efficient

training techniques, procedures and aircraft instrumentation will provide a significant reduction in the overall visual workload of the aviator during helicopter operations.

METHOD

Apparatus. The equipment utilized to record visual performance by the corneal reflection technique included the NAC Eye Mark Recorder, a LOCAM high speed motion picture camera, special high speed film, and the Helicopter In-flight Monitoring System (HIMS).

NAC Eye Mark Recorder. The basic device employed to study visual performance/workload was the NAC Eye Mark Recorder. By utilizing the NAC, the viewing point and movement of the eye can be detected and recorded. Through this optical device an illuminated reticle is focused on the cornea and reflected by mirrors to record movement of the eyeball such that the reticle always coincides with the eye viewing point. This illuminated reticle is superimposed on a primary image and may be recorded on 16mm film. The general specifications of this system are presented in Table 1 and an illustration of the NAC is provided in Figure 1.

TABLE 1

General Specifications of the NAC Eye Mark Recorder

Field-of-View:	30° type; vertical 22.7°, horizontal 31.4° 60° type; vertical 43.5°, horizontal 60° (Head can be freely moved.)
Eye Mark Size:	0.5mm (.02 in.) V mark on 16mm film
Aperture:	T8
Distance Between Subj & Object:	25cm (9.84") - infinity
Eye Mark Correction Range:	Full frame of 16mm film
Spot Lamp (Eye lamp):	Tungsten lamp Life 100 hours (at 3V use)
Mounting Adjustment:	The device can be adjusted to fit to any head size.
Distance from Eyeball to Half Mirror:	30° type; 35mm - 45mm (1.38" to 1.78") 60° type; 45mm - 55mm (1.78" to 2.16")
Parallax Adjustment Range:	15° downward
Optical Fiber:	Single strand diameter 20mm Effective picture 4 x 5mm Total length 1000mm (39.37")
Power Supply:	3 "D" size batteries in series for reticle illumination and alignment function
Weight:	Body 380g (13.4 oz.) Optical fiber 150g (5.3 oz.) Camera adapter 280g (9.9 oz.)

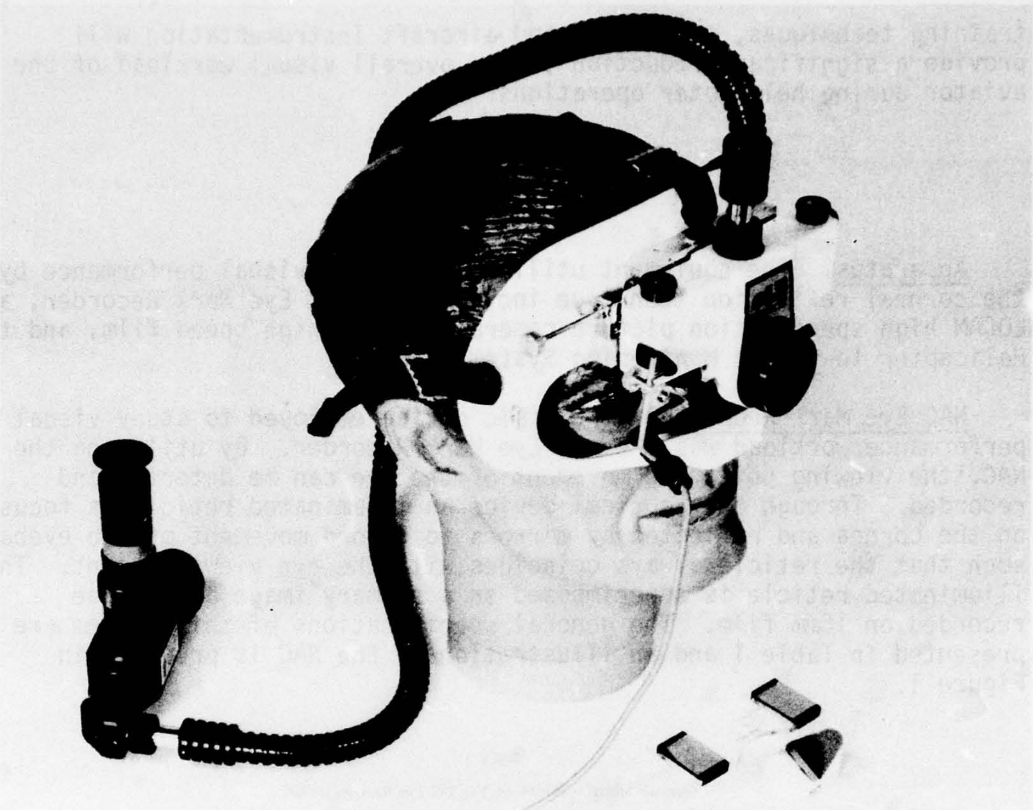

Figure 1. Basic NAC Eye Mark Recorder

The NAC basic structure is a hard plastic mask with pads which are adjustable by means of velcro tabs. The mask is secured to the face by nylon straps located over and around the head. An image lens which references the subject's field of view is located on the facial centerline and above the eyes. The scene referenced by this lens is transferred through the optical fiber bundle extending over the subject's head to a 16mm camera. The eye lamp is located slightly to the side and below the right eye. This unit provides the light source to the reticle which reflects off the eye. The half mirrors located in front of the eyes reflect the reticle through the eye mark optical recording path and superimpose the reticle on the recorded scene.

Adjustments and calibrations are accomplished by means of the xy adjusters, image lens knob, parallax adjustment knob, and eye mark focus dial. The xy adjusters are located on the mask next to the subject's left eye and provide xy fine adjustment for aligning the position of the eye mark. The image lens knob is located above the left eye and permits adjustment for the brightness of the field of view from T8 to T32. A

parallax adjustment knob is located next to the right eye. This knob is provided to permit eye movement data acquisition in cases where short distance viewing (i.e., reading maps or books) is required. This adjustment is required only when the eye position exceeds a 15^{o} downward motion. An eye mark focus dial is provided and located above the right eye to permit correction for individual distance differences between the reflective mirror and eye position.

The recording adapter for the NAC is illustrated in Figure 2. The small end is directly interlocked with the optical fiber bundle while the opposite end utilizes a "C" mount ring to link the NAC system to a camera. The top of the adapter permits observation of the eye mark integrated into the visual scene and is also used to monitor adjustments and corrections. Adjustments and calibrations are accomplished by shining a beam of light through this recording adapter and moving the xy adjusters so that the 5mm diameter spot is superimposed on the cornea of the eye.

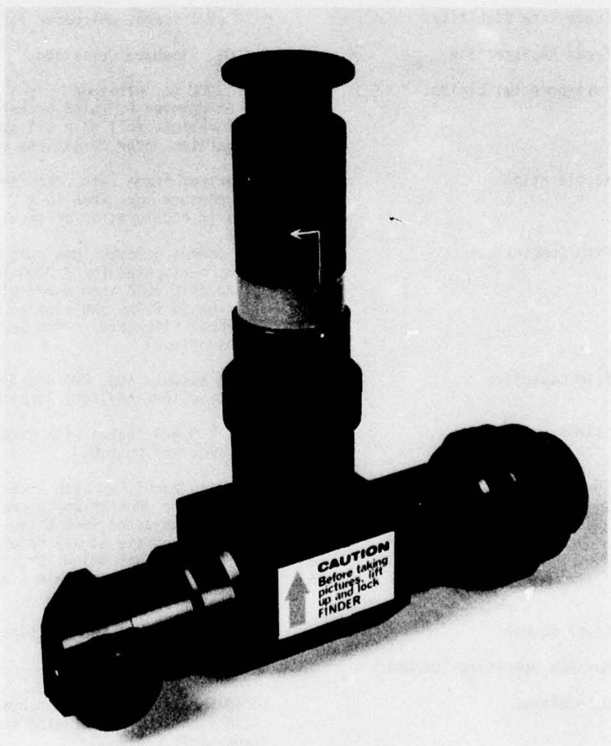

Figure 2. Recording Adapter for the NAC

Camera. The camera arrangement consisted of a LOCAM model 51-0002, high speed motion picture camera, with a model 51-0088 BCD camera decoder; and a Model 13-0007 time code generator, all manufactured by Redlake Corporation. Specifications for the camera, BCD decoder and generator are presented in Tables 2, 3, and 4, respectively.

TABLE 2

General Specifications of the LOCAM Model 51-0002 Camera

Lens Mount:	"C" Mount with 0.690 ± 0.0005 inches lens seat to film plane.
Electrical Connector:	The power connector at the rear of the camera is a 19 Pin Deutsch DM9601-19P connector.
Film Footage Indicator:	Displacement type footage counter, showing remaining film with scales for 100, 200 and 400 foot spools.
Operational Specifications	
Frame Rate:	Model 51-0002, infinitely variable between 16 and 500 FPS.
Frame Rate Stability:	± 1% or 1 frame, whichever is greater.
Frame Registration:	0.00013 Standard deviation.
Environmental Limits:	a) 60,000 ft. altitude b) -65 degrees F. (with heaters) c) Vibrations to 10g in all axes d) Operates under conditions of 95% RH.
Acceleration:	At maximum frame rate, the camera will not consume more than 10 ± 2 feet of film in acceleration or deceleration.
Film Specification:	This camera accepts 16mm acetate-based films perforated for 0.3000 inch long pitch or 0.2994 inch short pitch. Thin-based films can also be used with optional film gate. (See Section 6-2 Accessories.)
Film Capacity:	Camera accepts 100, 200 and 400 foot standard 16mm daylight loading spools.
Film Aperture:	0.292 X 0.410 inches with fiducials on one side and bottom.
Shutter:	Camera is furnished with a variable double disc shutter which can be manually adjusted from 0^{o} to 160^{o}. Shutters operate at 1/2 camera speed. For precise work below 20^{o}, it is recommended that a single fixed blade shutter be utilized.
Power Source:	Model 51-0002: 28 +3, -0 volts DC
Maximum Operating Current:	Model 51-0002: 8.5 Amperes
Dimensions:	10.00 inches Lg. X 3.78 inches Wd. X 7.38 inches Hi. (excluding knob and lens; Ref: Fig 1-1)
Weight:	11 lbs. (excluding lens, film, and dovetail mount)

TABLE 3

General Specifications of the BCD Decoder Model 51-0088

Format:	4 x 9 matrix (9 digits BCD).
Input:	9 digits multiplexed BCD (parallel bit, serial digit).
Input Impedance:	50 Ohms (each line).
Print Sync:	Camera shutter correlation pulse commands display printout every frame during exposure.
Exposure:	A four-position switch permits selection of the adequate exposure for different film sensitivities.
Operation:	The recording head is mounted on the pressure plate, imprinting film through the base. Display is located on the right side (viewing film upside up) next to the image area, with the most significant digit on top and the most significant bit next to the frame.
Temp Range:	0C to 70C (32F to 158F), operational.
Package:	The on-camera decoder is housed in a 8 x 5 x 2 case mounted on the motor compartment cover plate of the Locam Camera.
Power:	The circuit is powered through the signal connector. 5V DC (4.75 to 5.25 V operational), .75 amp, nominal required.

TABLE 4

General Specifications of the Time Code Generator Model 13-0007

Output Format:	9 Digits (hrs, min, sec, millisec). BCD Code, multiplexed (parallel bit, serial digit).
Panel Readout:	6 Digits (hrs, min, sec), Numeric LED display.
Accuracy:	1 PPM (.0001 %)/-20C to 70C (-4F to 158F); 1 PPM (.0001 %)/Month.
Sync Input:	Modulated or demodulated IRIG "B", at 0.5V to 20V pk. When present, this signal takes over timing control, which returns to internal time base when interrupted.
Time Code:	Selectable, actual IRIG time or arbitrary zero reference through time zero-reset input.
Other Codes:	Up to four digits (hrs and min places) can be set manually or by external BCD source (current syncing logic).
Temp Range:	0C to 70C (32F to 158F), operational.
Outputs:	2 parallel channels, up to 500 ft. of 50 to 500 ohm cable, unbalanced, coaxial or twisted pairs, at TTL levels.
Package:	6 x 6 x 9 in. drawn can with rubber lid seal.
Power:	28 VDC (21 to 30 VDC operational), 2.5A max. Provision for external battery input with automatic (internal) switching.

Figure 3 illustrates the NAC/Camera arrangement. The LOCAM camera with BCD decoder is located to the far left of the picture. The recording adapter links the NAC recorder to the camera. Directly behind the camera is a (30 Vdc) battery supply which provides power for the time generator located to the right of the NAC. The smaller box is a modified power supply for the NAC and will be discussed later. The camera allows NAC data to be recorded on 400 foot, 16mm film at 16 frames per second. This footage is equivalent to approximately 15 minutes of data collection time. The time generator permits each frame of film to be coded with subject number, subject run, and real time in hours, minutes, seconds and milliseconds. Ease of handling and quick disconnections allow cameras to be switched with only two minutes of down time between subject runs.

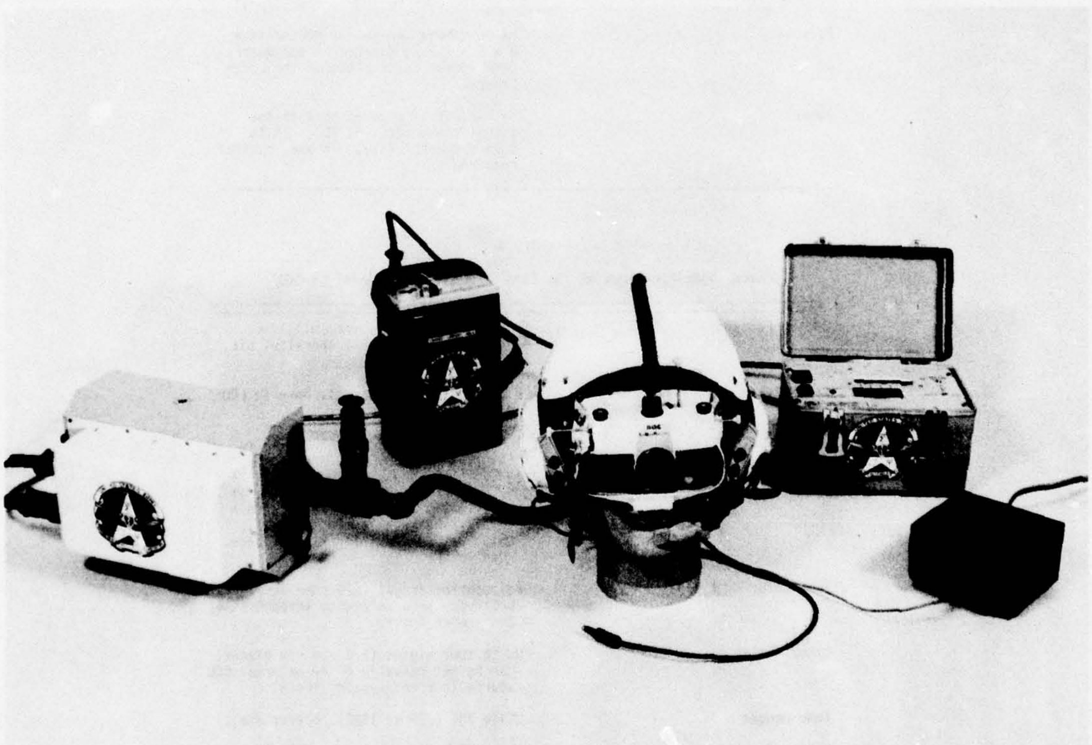

Figure 3. NAC/Camera System Arrangement

Film and Lighting. As with any form of photography, the type film and lighting are critical items for favorable NAC data collection. In 1973, the laboratory realized the limitations of video tape (Figure 4) and switched to Kodak, high speed, daylight, Ektachrome E.F. color motion picture film (ASA 160/400 ft x 16mm). The film was exposed and processed by normal procedures. Although the use of film was a decided improvement over video tape, two shortcomings were still noted when this technique was used. First, contrast problems were observed when attempts were made to photograph both inside and outside the aircraft; and second, a critical illuminance problem limited data collection operations to about three hours per day. To correct these deficiencies, the laboratory converted to Kodak 4X negative black and white film (ASA 500/400 ft. X 16mm) in March 1975. The film was processed by developing a working positive print on Eastman reversal black and white print film (Figure 5). This change in film did not resolve the contrast issue but did extend the useful hours for photographing.

Figure 4. Video Tape of NAC Data

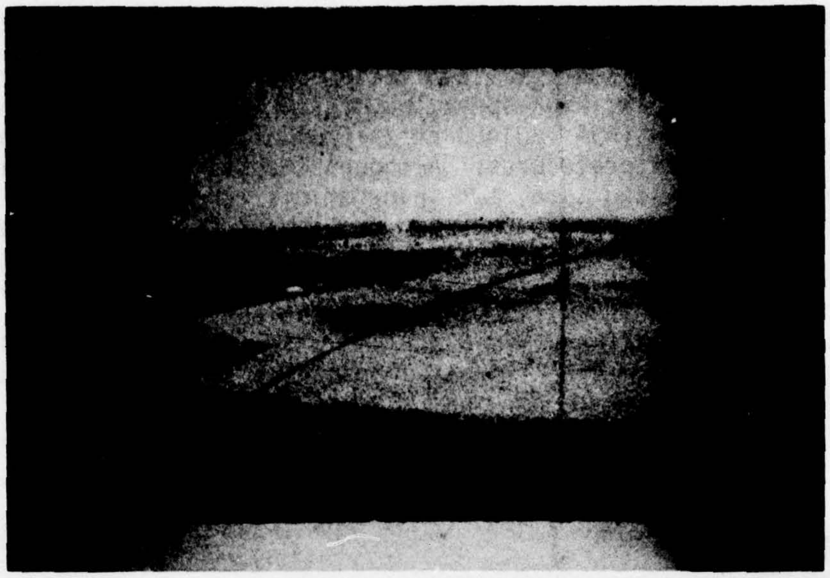

Figure 5. Black & White Motion Picture of NAC Data

Finally, in June 1976, by utilizing Kodak high speed, daylight 434 7241 E.F. Ektachrome color film (ASA 160/400 ft x 16mm) and a light blue template around the instruments, the laboratory was able to film both inside and outside the aircraft as shown in Figure 6. To achieve these results, the film had to be exposed and processed at ASA 640.

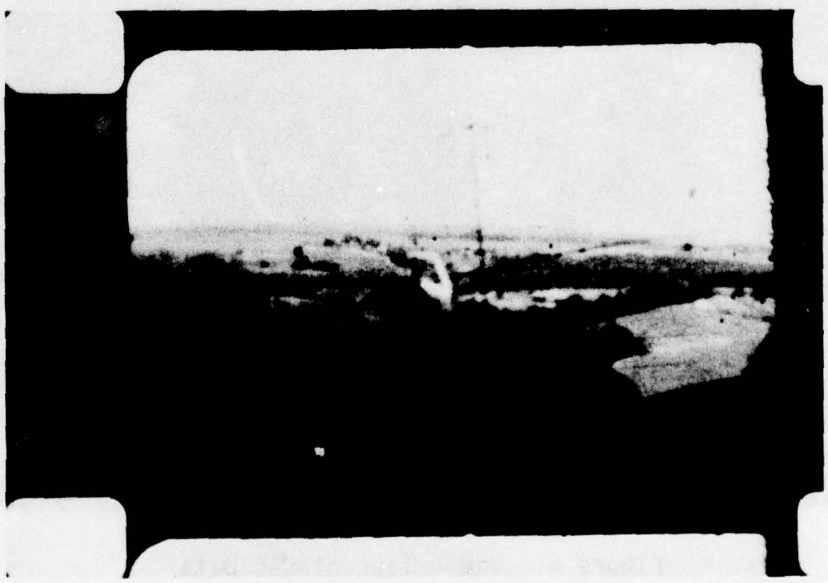

Figure 6. Color Motion Picture of NAC Data

Through use of this film and special processing techniques, some guidelines for collecting favorable data were established. First, data collection could be accomplished whenever the sun angle was greater than 50° above the horizon. Filming could be accomplished in any direction except within 10° directly into the sun, at which time a "wash out" effect occurred. (This rule was not restrictive to flights below the horizon within two hundred feet absolute). Finally, after correcting for light degradation caused by deterioration of the optic bundle, a table was devised to determine the correct "T" stop for each luminance level. The bundle used by the laboratory had an approximate 3.3 T-stops light loss. Light level readings were derived from the average reflective light off the instrument panel and below the horizon. The values to determine each "T" stop for the NAC are referenced in Table 5.

TABLE 5

USAARL's "T" Stop Scale for the NAC Recorder

	Panel (Ft. L.)	Below Horizon (Ft. L.)
T8	11.75	31.4
T11	23.55	62.8
T16	47.10	125
T22	93.90	251
T32	188	753

HIMS. In addition to the NAC recorder and camera system, in-flight performance measures of psychomotor performance as well as aircraft performance were obtained via the USAARL Helicopter In-flight Monitoring System (HIMS). The HIMS measures pilot's cyclic, collective and pedal inputs and simultaneously records the aircraft responses to include position, acceleration, and rate changes. Twenty channels of continuous information are recorded in real time on an incremental tape recorder. The recorded values are then reduced and analyzed on ground based digital computers. The navigator is shown in Figure 7, the digital recorder in Figure 8 and a sample computer printout in Figure 9. A full report of the system is available in USAARL Report No. 72-11.[12]

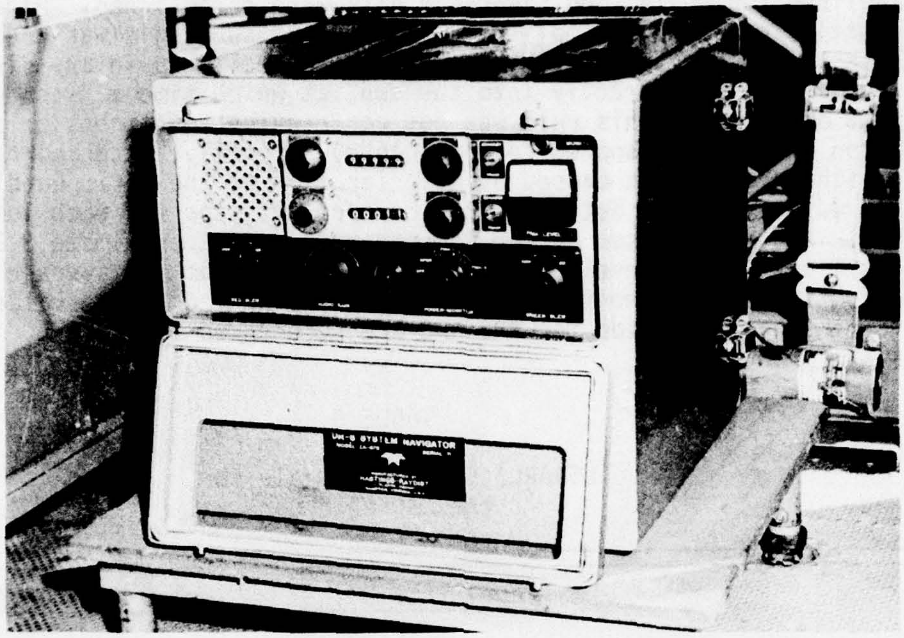

Figure 7. The Navigator - Part of the HIMS

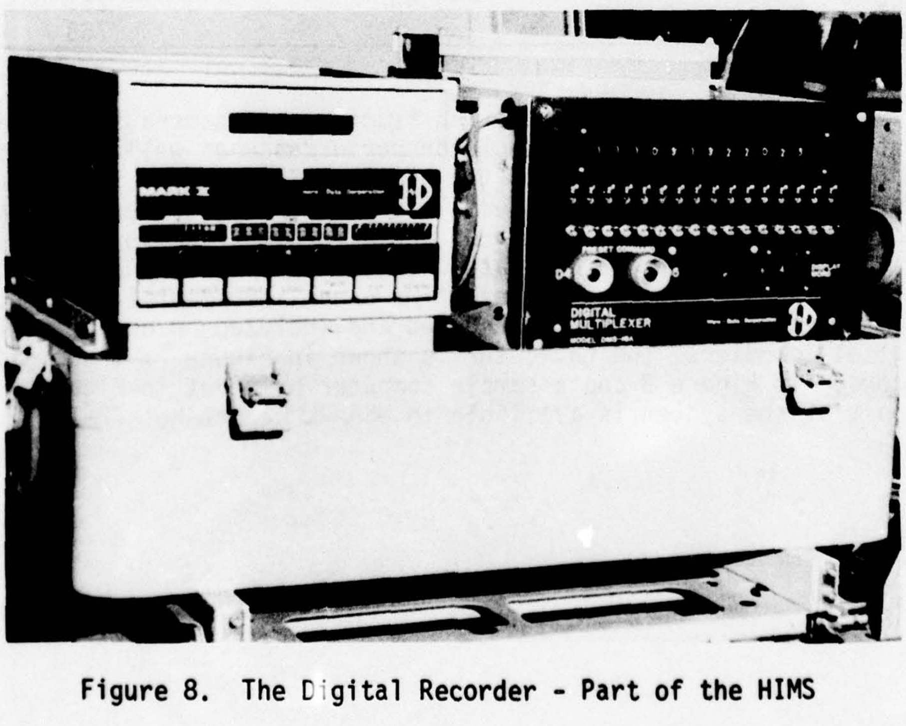

Figure 8. The Digital Recorder - Part of the HIMS

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TIME HISTORY LISTING PAGE 117

STUDY 1 RUN 0 3 DATA 1 17 0 67 4 TEMP(C) 1 6 PRESSURE 0 7

PITCH	ROLL	HDNG	X	Y	AX	AY	AZ	ROL-R	PIT-R	YAW-R	CYCAF	CYCLR	COLL	THROT	PEDLR	RPM	ALTR	ALTB	A/S	MIN	SEC	DIST
3.5	1.2	317.4	9	0	0.03	-0.05	0.99	-1.0	1.8	3.3	-0.26	-0.72	4.64	97.9	-1.78	330.0	5.	230.	17.	9	38	9
3.7	-0.7	319.5	9	0	0.03	-0.05	0.96	1.1	1.5	4.3	-0.39	-0.70	4.66	97.9	-2.04	330.1	7.	224.	16.	9	39	9
3.5	0.7	321.8	9	0	0.04	-0.04	0.98	-0.4	2.0	3.2	-0.26	-0.90	4.70	97.7	-2.29	329.1	5.	224.	18.	9	40	9
3.7	-0.5	321.5	9	0	0.06	-0.02	0.99	-0.4	2.0	2.4	-0.28	-0.51	4.77	97.7	-2.24	329.1	5.	224.	17.	9	41	9
4.3	0.2	320.2	9	0	0.06	-0.06	0.99	-0.1	2.0	2.7	-0.51	-0.67	4.81	97.7	-1.94	330.0	5.	230.	18.	9	42	9
4.3	0.4	320.4	9	0	0.06	-0.04	0.97	-0.0	1.8	1.5	-0.57	-0.69	4.74	97.9	-2.12	330.0	7.	224.	18.	9	43	9
3.5	0.4	318.5	9	0	0.05	-0.05	0.96	0.6	1.2	0.2	-0.59	-0.51	4.67	97.7	-1.78	330.0	7.	224.	17.	9	44	9
2.8	0.9	316.9	9	0	0.06	-0.05	0.98	-0.8	2.3	1.6	-0.16	-0.67	4.68	97.7	-1.91	330.1	7.	230.	16.	9	45	9
3.7	-0.7	318.3	9	0	0.05	-0.07	0.98	-0.8	2.1	3.8	-0.52	-0.87	4.78	97.7	-2.31	329.1	7.	230.	15.	9	46	9
3.9	-0.4	319.2	9	0	0.05	-0.06	1.02	0.4	2.0	2.4	-0.46	-0.67	4.78	97.7	-2.14	328.7	10.	219.	15.	9	47	9
3.7	0.4	319.4	9	0	0.03	-0.05	1.00	-0.6	1.6	2.4	-0.54	-0.46	4.78	97.7	-2.18	330.0	7.	224.	16.	9	48	9
3.9	0.9	319.0	9	0	0.08	0.00	0.98	2.9	2.7	1.8	-0.62	-0.32	4.79	97.5	-2.00	330.0	7.	230.	16.	9	49	9
5.0	3.0	316.0	9	0	0.08	-0.03	0.98	-1.6	2.1	-0.4	-1.04	-0.35	4.86	97.9	-1.78	329.8	5.	224.	17.	9	50	9
3.7	-0.2	314.8	9	0	0.08	-0.05	0.98	-1.1	1.1	2.3	-0.52	-0.69	4.91	97.5	-2.07	330.0	7.	224.	16.	9	51	9
3.0	-0.4	315.7	12	0	0.06	-0.04	1.01	-0.4	1.5	2.5	-0.61	-0.69	4.91	97.9	-2.18	329.1	5.	224.	16.	9	52	12
2.8	-0.7	315.1	12	0	0.06	-0.06	1.00	1.5	1.9	1.1	-0.52	-0.60	4.77	97.7	-1.76	329.8	10.	230.	17.	9	53	12
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4.0	1.2	316.5	12	0	0.06	-0.06	0.97	1.1	2.0	3.3	-0.87	-0.43	4.68	97.9	-1.92	329.8	10.	224.	15.	9	55	12
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3.5	-0.4	316.0	12	0	0.02	-0.06	0.97	-0.0	2.3	3.0	-0.34	-0.54	4.78	97.7	-2.05	329.8	7.	224.	16.	9	57	12
4.1	-0.7	316.9	12	0	0.05	-0.06	0.98	-0.7	1.8	3.1	-0.51	-0.60	4.78	97.7	-2.06	330.1	7.	224.	16.	9	58	12
4.3	-0.7	317.6	12	0	0.06	-0.06	0.96	0.9	1.6	2.8	-0.49	-0.35	4.71	97.9	-2.07	330.1	10.	230.	16.	9	59	12
4.1	0.9	317.3	9	0	0.05	-0.05	1.00	0.3	2.4	1.6	-0.66	-0.63	4.72	97.9	-1.96	329.6	10.	230.	16.	10	0	16
4.6	-1.3	315.7	9	0	0.08	-0.05	0.97	-0.7	1.9	1.3	-0.77	-0.43	4.72	97.5	-1.93	330.3	7.	224.	16.	10	1	16
4.3	-0.2	314.4	9	0	0.06	-0.05	0.99	-0.3	1.5	2.0	-0.64	-0.57	4.79	97.7	-1.85	330.1	7.	224.	17.	10	2	16
3.2	-1.4	314.1	9	0	0.05	-0.08	0.98	-0.0	1.3	1.0	-0.51	-0.51	4.78	97.7	-1.88	329.6	10.	224.	17.	10	3	16
2.8	0.2	312.7	9	0	0.03	-0.08	0.97	1.0	2.3	1.3	-0.41	-0.46	4.78	97.5	-1.78	329.8	7.	224.	16.	10	4	16
4.1	0.7	311.8	9	0	0.06	-0.05	0.98	-0.7	2.8	2.5	-0.76	-0.31	4.76	97.9	-1.73	330.8	10.	224.	16.	10	5	16
4.1	-0.4	312.5	9	0	0.06	-0.06	0.95	0.1	1.5	2.8	-0.51	-0.58	4.75	97.7	-1.91	330.4	5.	224.	16.	10	6	16
3.5	0.7	313.0	12	0	0.06	-0.06	0.98	-0.9	1.9	1.1	-0.39	-0.58	4.76	97.7	-1.80	329.6	5.	230.	16.	10	7	19
3.9	-1.3	311.8	12	0	0.06	-0.09	0.98	-1.0	1.9	2.5	-0.61	-0.43	4.75	97.7	-1.58	330.4	7.	230.	17.	10	8	19
3.9	-0.7	313.7	12	0	0.04	-0.05	0.98	-0.3	1.8	4.6	-0.52	-0.51	4.74	97.7	-1.83	330.4	10.	224.	17.	10	9	19
3.7	0.2	315.0	12	0	0.05	-0.05	0.98	1.6	1.8	2.4	-0.36	-0.54	4.74	97.7	-1.80	329.8	12.	230.	17.	10	10	19
4.3	-0.2	314.8	12	0	0.04	-0.06	0.95	-1.2	1.6	3.1	-0.82	-0.47	4.74	97.7	-1.80	330.3	10.	219.	17.	10	11	19
3.5	0.2	316.0	12	0	0.06	-0.05	0.96	0.8	1.8	2.9	-0.52	-0.46	4.64	97.5	-1.88	330.3	10.	224.	16.	10	12	19
3.5	0.5	315.7	12	0	0.05	-0.06	0.96	0.8	1.8	1.5	-0.49	-0.64	4.64	97.7	-1.76	330.0	10.	230.	15.	10	13	19
2.8	0.5	312.7	12	0	0.06	-0.05	0.98	-2.2	1.9	0.6	-0.34	-0.72	4.66	97.7	-1.61	330.3	7.	219.	16.	10	14	19
3.3	-1.4	311.6	12	0	0.04	-0.06	0.97	-0.2	2.4	3.1	-0.61	-0.60	4.65	97.9	-1.59	330.9	7.	219.	16.	10	15	19
3.9	-2.0	313.2	12	0	0.06	-0.06	0.98	0.1	1.6	2.4	-0.41	-0.57	4.66	97.7	-1.65	330.4	7.	224.	16.	10	16	19
3.5	0.5	313.4	12	0	0.04	-0.06	0.96	2.1	1.6	3.1	-0.31	-0.47	4.65	97.5	-1.60	330.4	10.	230.	16.	10	17	19
3.5	0.7	313.9	12	0	0.03	-0.04	1.02	0.4	2.3	2.6	-0.39	-0.47	4.70	97.9	-1.64	330.1	10.	224.	17.	10	18	19
4.3	0.7	314.1	12	0	0.06	-0.05	0.98	-0.7	2.1	2.6	-0.66	-0.46	4.75	97.5	-1.63	330.1	7.	224.	16.	10	19	19
3.7	0.4	315.5	12	0	0.08	-0.05	1.00	-1.1	1.2	3.8	-0.36	-0.67	4.73	97.5	-1.77	330.4	7.	230.	16.	10	20	19
3.5	-0.5	317.1	12	0	0.06	-0.05	0.96	0.2	2.2	2.8	-0.56	-0.66	4.57	97.7	-1.83	330.6	10.	224.	16.	10	21	19
3.3	0.9	317.3	18	0	0.05	-0.05	0.97	-0.2	1.7	2.4	-0.37	-0.66	4.59	97.7	-1.70	330.8	7.	224.	16.	10	22	25
3.7	-0.2	316.7	18	0	0.06	-0.06	0.97	0.5	2.5	2.0	-0.52	-0.57	4.59	97.9	-1.70	330.6	10.	224.	17.	10	23	25
3.7	0.9	316.5	18	0	0.06	-0.05	0.98	-0.9	1.4	2.2	-0.56	-0.58	4.60	97.9	-1.64	330.4	10.	230.	16.	10	24	25
3.0	-0.0	315.8	18	0	0.06	-0.06	0.98	-1.1	2.0	1.7	-0.14	-0.73	4.60	97.7	-1.80	330.0	10.	224.	17.	10	25	25
3.7	-0.7	314.6	18	0	0.08	-0.04	0.98	0.9	2.4	1.3	-0.46	-0.41	4.72	97.7	-1.66	330.0	5.	224.	16.	10	26	25
4.6	1.6	313.7	18	0	0.06	-0.06	0.97	0.2	2.5	2.6	-0.72	-0.58	4.69	97.7	-1.68	330.4	5.	224.	16.	10	27	25
4.3	-0.7	314.1	18	0	0.06	-0.06	1.00	-0.7	1.5	2.6	-0.31	-0.61	4.66	97.5	-1.69	330.3	5.	224.	16.	10	28	25
3.7	-0.0	314.1	18	0	0.05	-0.06	0.96	0.3	1.6	2.9	-0.29	-0.61	4.56	97.9	-1.70	330.9	7.	224.	17.	10	29	25
3.5	-0.4	315.1	18	0	0.05	-0.02	0.95	-0.6	1.8	2.5	-0.61	-0.51	4.58	97.7	-1.75	330.3	2.	224.	17.	10	30	25
3.3	-0.2	315.8	18	0	0.00	-0.06	0.96	1.0	2.0	2.9	-0.51	-0.47	4.57	97.5	-1.75	330.4	7.	230.	16.	10	31	25
3.5	1.6	317.6	18	0	0.00	-0.05	0.99	-0.5	2.1	3.9	-0.46	-0.60	4.72	97.5	-1.90	330.0	7.	219.	16.	10	32	25

Figure 9. HIMS Computer Printout

The time code generator of the BCD camera decoder was synchronized with the internal time code generator of the HIMS. This time was printed on each frame of film as well as each second of performance data from the HIMS, thus visual data was synchronized with performance data.

<u>Visual Free Time Chart</u>. A visual free time chart similar to that utilized by Bell Helicopter Corporation[13] was designed to assist in determining pilot visual time which was not essential for aircraft management. The chart measured 14 X 9.5mm with 2mm lettering (Table 6). The words selected were random, meaningless, and monosyllabic. The chart was positioned on the instrument panel of the JUH-1 helicopter within visual range of the subject pilot.

TABLE 6

Visual Free Time Chart
feed sly as badge gape wrath pun cloth sick love rough kept calf
Greek beck nigh flop roe thick best fall choose flap jag frock chop
wasp true cheat tongue ode pass wink hitch hull browse zone kill
bog fee punt odds rooms lag shove kid fowl thigh hill trade bind
reap chart black scare writ wait high mast wife cob rind fling rot
pipe clothes mash vase good gage eyes rode lend forge raise sniff
puff yawn prime deep inch watch scan shank bronze thud grope
ray solve tug sup gap bathe curse slouch crib add owls thus clod
pus rear nose prig eat shine grudge flick dad gasp by wheeze
bored woo am roll slide though nine look ease act wire freak
queen dwarf aim spice jell scout shaft hum forth sledge south woe

Data Analysis Equipment. Equipment utilized for the reduction and analysis of the NAC data is listed in Table 7. The function of all equipment referenced is according to manufacturer's specifications.

TABLE 7

Data Analysis Equipment

	Company	Item	Model
1.	L&W	16mm Variable Speed Data Analyzer	Model 224A
2.	Hewlett Packard	Preset Counter	Model 5330B
3.	Hewlett Packard	Digital Voltmeter	Model 3480B
4.	Wang	Advanced Programing Calculator	Model 720
5.	Wang	Dual Magnetic Tape Cassette Reader/Recorder	Model 709
6.	Wang	High Speed Printer	Model 721
7.	Wang	Micro Interfacer	Model 705
8.	Wang	Input/Output Writer	Model 711
9.	Wang	Disc Drive	Model 710
10.	USAARL	12 Micro Switch Keyboard	

Modifications. The equipment shown in Figure 3 was compatible, as designed by the manufacturer, to document oculomotor performance in a laboratory setting. However, from the experience of the Aviation Psychology Division of the US Army Aeromedical Research Laboratory (USAARL), several modifications to the basic system were accomplished to provide a compatible system with the helicopter flight environment. Among the primary issues which had to be resolved were: calibration of the system; protection of the optic bundle; comfort of the mask for the subjects; and added stability for the mask to prevent misalignment of adjustment caused by the extreme vibration of the helicopter.

The modifications which were made to the mask to increase stability and provide more comfort for the subject are illustrated in Figure 10. The basic mask provided a padded "V" nose piece and nylon straps attached to three points on the mask which were at the top and on either side of the mask. This laboratory's modification was to remove the nose "V" and attach additional padding along sharp metal edges of the mask located along the forehead and bridge of the subject's nose. These locations were the most common points of discomfort caused by the mask. By attaching additional snaps on the mask above each of the existing side snaps, the mask was adjusted to assume an improved, flatter position on the subject's forehead. This allowed the lower straps to

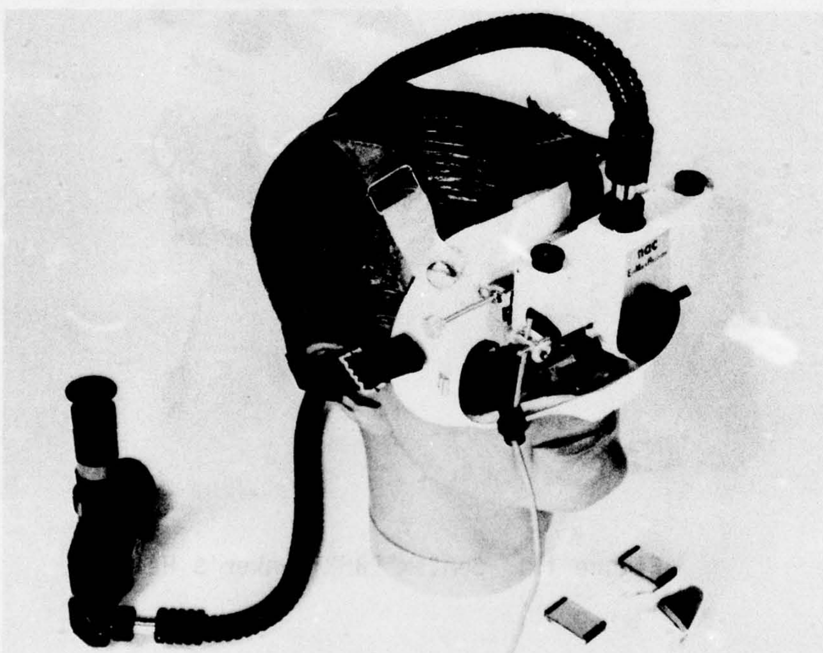

Figure 10. Modifications to NAC System

fit under the occipital protuberance of the skull. The second set of straps were attached at about the Lambda and crossed laterally above the ears to the mask. The last strap started at the Lambda and ran anteriorly over the sagittal suture and frontal bone to the mask. These improvements relieved subject discomfort and provided needed stability.

The modification to the mask configuration was completed by the integration of a Gentex PBH2 tanker's helmet (Figure 11). Because the PBH2 helmet differed from the SPH4 aviator's helmet, in that it has a higher forehead protection plate, the PBH2 could be worn with the NAC recorder, while simultaneously affording head and ear protection in addition to increased stability for the total system. Additional nylon straps with snap connectors were attached to the top and back of the helmet to secure and protect the optic bundle.

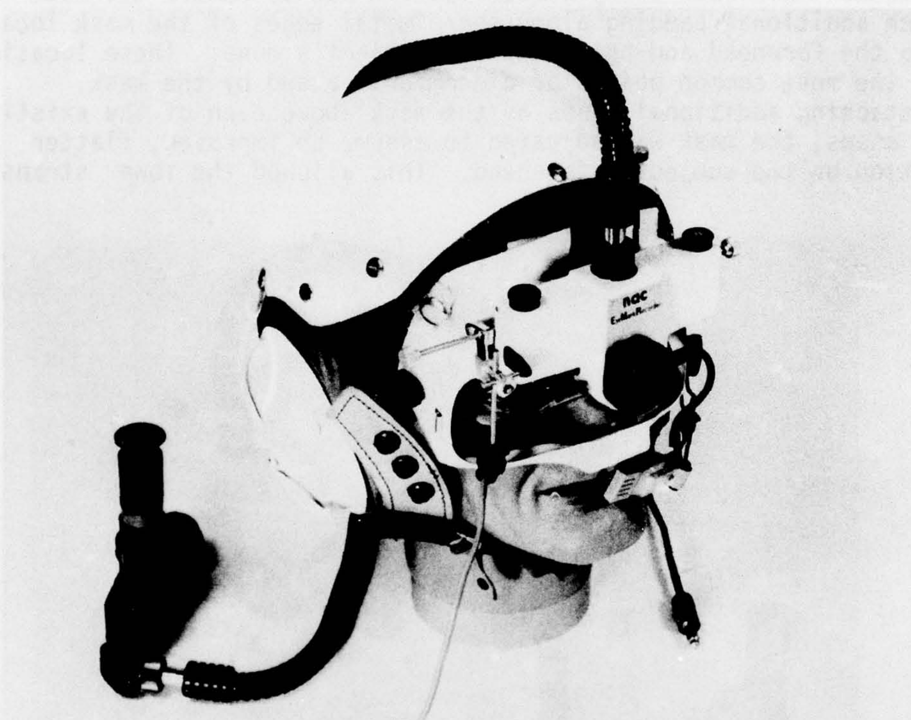

Figure 11. Gentex PBH2 Tanker's Helmet

A variable power supply was designed and fabricated by the laboratory (Figure 12) to aid in optimizing the maximum continued 5mm reticle from the eye lamp. The power supply utilized 28 Vdc aircraft power and provided a variable output of 1 to 5 Vdc. This unit supplanted the NAC recorder's normal "D" cell battery pack thus decreasing the risk of battery deterioration and power loss. In addition, an assortment of half mirrors with varying reflective characteristics were utilized to provide the best reticle possible for different luminance conditions.

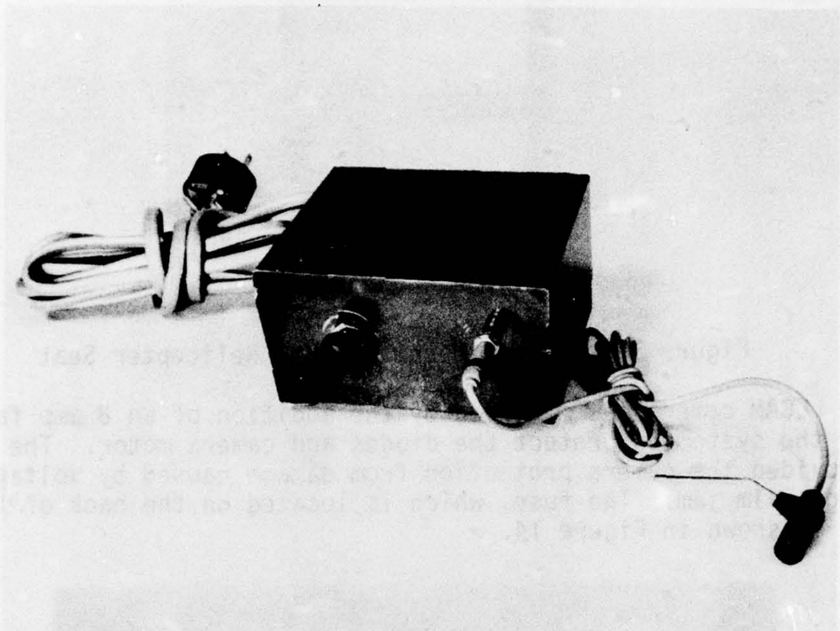

Figure 12. USAARL's Variable NAC Power Supply

To secure the LOCAM camera in the USAARL JUH-1 helicopter a special mount was fabricated from heavy gauge aluminum and fastened to the back of the subject pilot's seat (Figure 13). The camera was attached to the mount with a Winter dovetail camera mount and receiver. This mounting system provided a more compact arrangement of system components, aided in protecting the optic bundle by moving the total camera/NAC system with any movement of the seat, and insured system stability during flight.

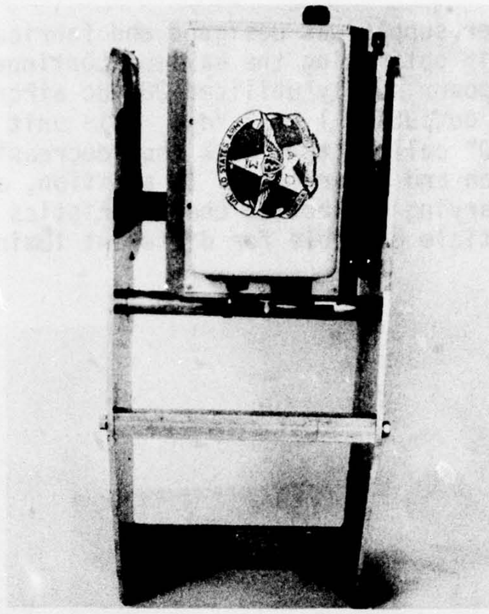

Figure 13. Camera Mount to UH-1 Helicopter Seat

The LOCAM camera was modified by the addition of an 8 amp fast blow fuse to the system to protect the diodes and camera motor. The 8 amp fuse provided the camera protection from damage caused by voltage transients or film jam. The fuse, which is located on the back of the main camera, is shown in Figure 14.

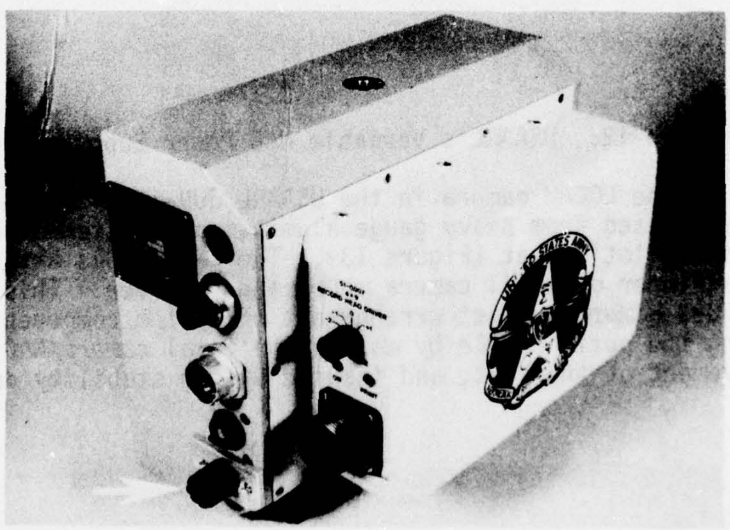

Figure 14. 8 Amp Fuse Added to LOCAM Camera

The final modification of the data collection system was the design and addition of a blue template which was placed over the existing instrument panel of the JUH-1 helicopter. A normal US Army instrument panel color was flat gray while this laboratory's was flat black. Neither panel allowed for proper contrast to photograph both inside and outside the aircraft. Through the use of a light blue template, this contrast problem was decreased to a minimal level.

PROCEDURE

Data Collection. The primary concern during the data collection phase was to assure the proper fitting of the NAC mask and the calibration/stabilization of the system. Without proper fitting the mask would cause discomfort within five to ten minutes of flight.

Initial fitting and calibration was performed in the laboratory with the subject seated and with numerous targets located in front of him to aid in calibration. After the basic mask, minus the optic bundle, and straps were fitted as previously discussed (refer to Figure 10), and the xy adjustment knobs were centered, a small pen light was used to "bore site" the crude adjustment of the NAC mask (Figure 15). The procedure was to focus the penlight so that its light would shine through the optic bundle receptacle of the mask, causing a 5mm dot to appear somewhere on the subject's right eye. The mask was then shifted so that the dot appeared directly in the center of the pupil of the right eye. After securing the mask for stabilization and comfort, the PBH2 helmet was fitted starting from the back and pulling it forward over the head. Once the helmet was on, chin strap fastened, and the mike boom adjusted, the mask was "bore sighted" again to assure that no significant changes in calibration had occurred.

The optic bundle was then connected and secured to the helmet and the recorder adapter added to the system. Again by placing the pen light in the monitoring section of the recorder adapter (Figure 2), and by manipulating the xy adjustment knobs, the 5mm dot could be centered on the pupil of the right eye. Finally, after connecting the eye lamp to the NAC power supply, the NAC recorder was fine adjusted by the normal procedures outlined in the instruction manual. The advantage of this modification to the procedure was that the investigator could fit and calibrate the NAC in a relatively short period of time and the modification provided maximum handling protection to the optic bundle, a critical item of the system.

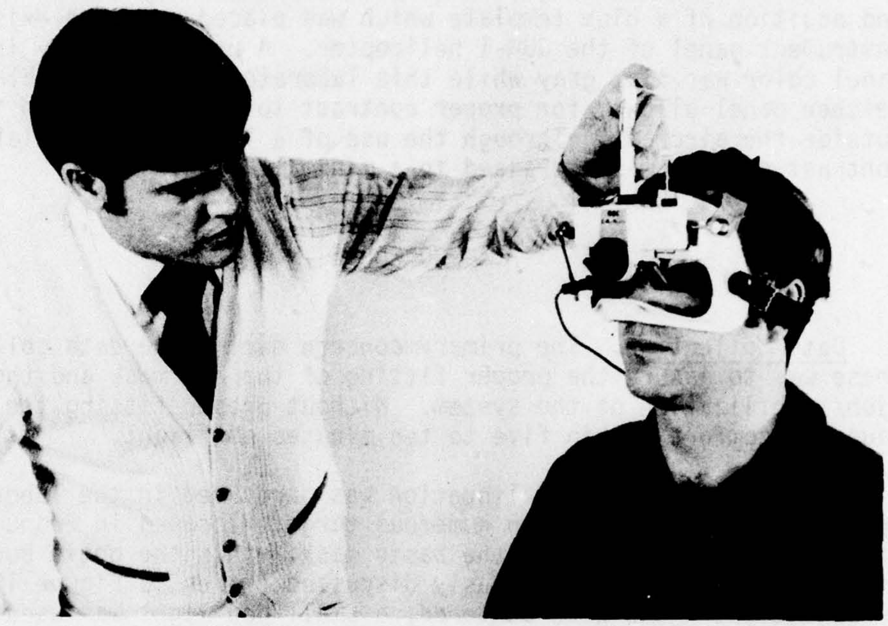

Figure 15. Crude Calibration of NAC System

After calibrating the NAC, and before proceeding to the helicopter, the recording adapter was removed from the bundle to facilitate ingress of the subject pilot. Once seated, the normal safety procedures of fastening restraints and checking communications were accomplished. The adapter was then reconnected to the bundle, the total system connected to the camera, and a fine adjustment of the NAC performed.

Before starting a test profile the helicopter was hovered for three to five minutes to allow the NAC time to "settle." This time was utilized to move the aircraft from the parking location to the test starting point. At this point, the NAC was fine adjusted a final time. *After adjustment, a changeover ring on the recorder adapter was switched* from the viewing position to recording and taped so that aircraft vibration would not cause slippage of the ring. After the test run was completed the reticle image was again checked to assure that no slippage had occurred during the flight. Previous studies have indicated that the corneal reflection technique has an overall accuracy of $\pm 2^{\circ}$ when used within $\pm 12.5^{\circ}$ of eye movement. Studies also indicated that head movement had to be considered any time eye movement was greater that 15° in any direction from the centrofoveal position.[1,8]

In an attempt to delineate the possible impact of errors caused by head rotation during flight, data were recorded on pilot head rotation

during helicopter flight and the effects of this rotation on the visual data were assessed (USAARL Report No. 74-7).[8] The results of this study and subsequent data indicate that not only was head rotation during laboratory performance testing quite different from that observed in the operational environment; but also that head rotation presented minimal error in the collection of visual performance data during actual helicopter flight.

To facilitate scoring of the data, the aircraft windscreen in front of the subject was partitioned into four equal sections using a grease pencil. Twenty-five millimeter tick marks were added to the division lines, which allowed the data depicted on different locations of the windscreen to be recorded and distances outside the aircraft to be calculated. During the actual test profile, the changeover ring of the recorder adapter was utilized to segment portions of the film. By varying the changover ring from recording to viewing, three to four frames of film were overexposed, thus providing a reference mark delineating the start of each separate film segment. Finally, to complement the completed system the visual free time chart was stationed on the instrument panel directly in front of the subject pilot. Although the NAC recorded total visual performance, the chart allowed the investigator to calculate the total free time in which the subject pilot was not utilizing critical cues to perform his assigned flight mission.

With a crew consisting of a safety pilot, HIMS operator, photographer, and flight coordinator, the subject pilots were directed to perform any helicopter maneuver under study. Each subjects' total visual performance was recorded in real time on (motion picture) film. After the film was processed, these data were ready for reduction and analysis.

Data Reduction. The data reduction room was arranged so the investigator could utilize the L&W 16mm analyzer to project the NAC film on a screen. As shown in Figure 16, the film was processed at one quarter speed or four frames per second. Through a prereduction preparation, the total area of any one frame was divided into 13 major viewing areas. As the reticle appeared in each of the 13 areas the investigator pressed the corresponding micro key on a switch keyboard (Figure 17) located on the table to his front. The micro switches were connected to the preset counter and the digital voltmeter to give each switch a selected voltage and an elapsed time for which the voltage selected was maintained. This information was transferred to the Wang disc drive through the micro interface and was stored. The Wang calculator and peripheral equipment is pictured in Figure 18.

After position and time data from the film had been stored on the disc, the data were then transferred to cassette tapes so that each individual flight segment of data could be selected, values computed,

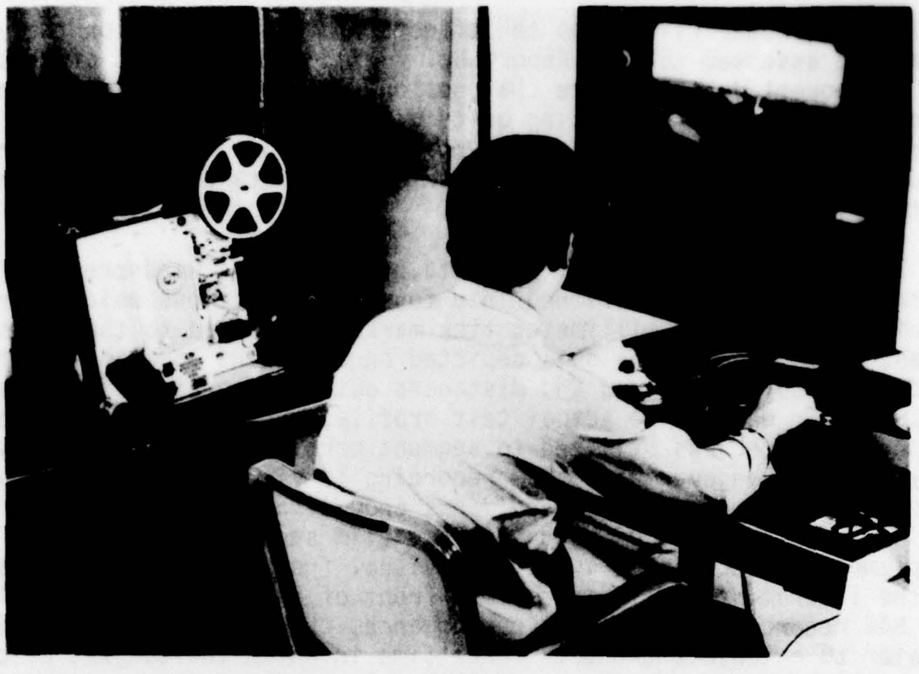

Figure 16. Data Reduction Using Projector and Wang Computer

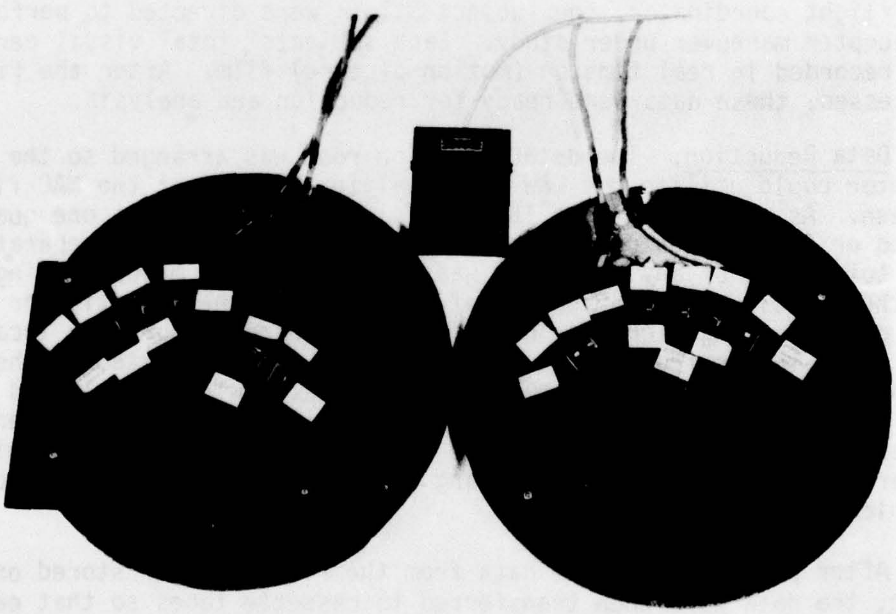

Figure 17. Micro Switch Keyboard

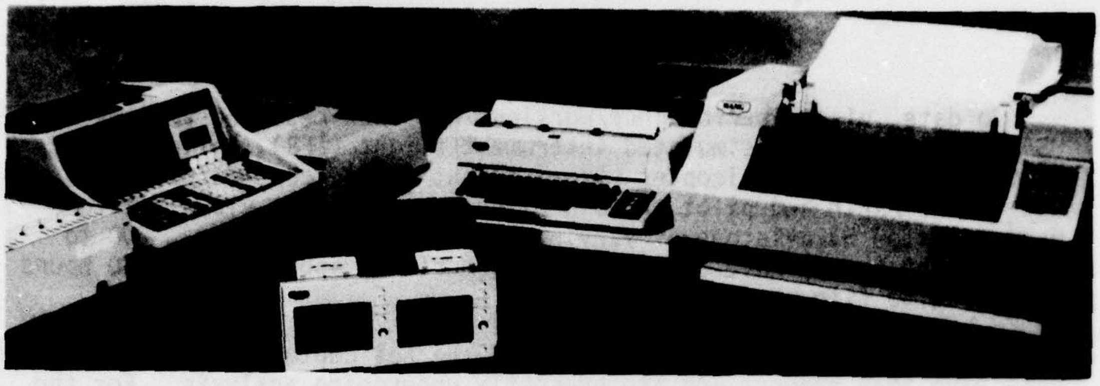

Figure 18. Wang Computer, Disc, and High Speed Printer

and results printed by the high speed printer. The final results, as demonstrated by Figure 19, gave the total time elapsed in each of the 13 zones, percent of the total time, frequency, mean time in each zone, and the standard deviation along with link values from each zone to all others. After each segment was computed, a master total was summed for the total film. The time for data reduction was approximately five hours for each one hour of data.

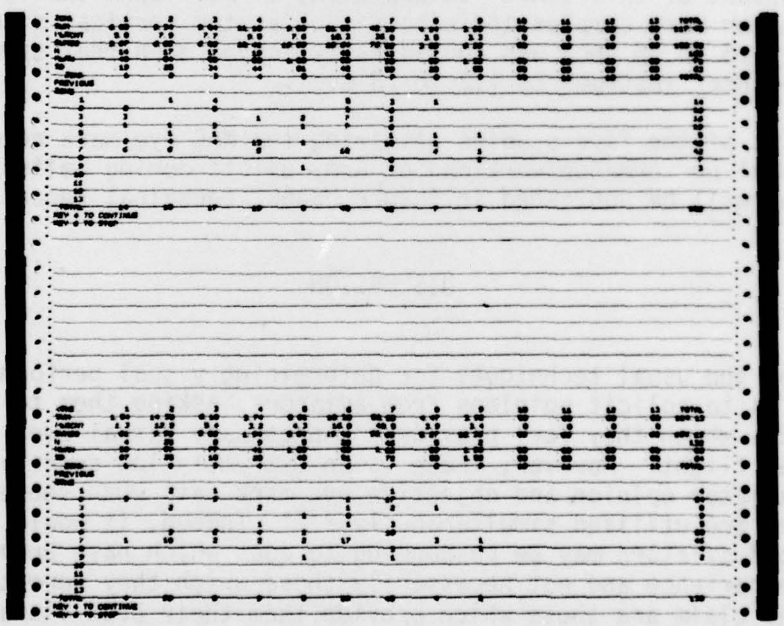

Figure 19. Visual Data Printout

APPLICATION

To date, visual performance/workload has been recorded via the USAARL method during simulated instrument flight (IFR), helicopter instrument flight, helicopter visual flight (VFR), copilot/navigator nap-of-the-earth and pilot terrain flights. In-flight visual performance data on 53 aviators of varying experience levels (i.e., 200 to 2500 flight hours) have been obtained comprising approximately 30 hours of real time film recordings.

The simulated instrument flight and the helicopter instrument flight data have been reduced and are presently undergoing analysis. For the simulator study, preliminary results utilizing multivariate analysis techniques indicate that the experience level of the two test groups (i.e., 200-hours flight experience and 1500-hours flight experience) was not a contributing factor to the percent of viewing time, mean dwell time, or frequency of use for particular instruments. For both the simulator and in-flight investigations, subjects utilized the vertical situation indicator and the horizontal situation indicator during the total flights approximately 43 percent and 26 percent of the time, respectively. The next most frequently utilized instrument comprised only 8 percent of the total viewing time and the total arrangement of the seven monitoring gauges (i.e., oil pressure and temperature) required only 2 percent of this time. In addition, it was found that the mean time spent on more complex indicators such as the vertical situation indicator (.5 to .6 sec) was considerably longer than that spent on one and two pointer instruments (.2 to .3 sec).

Results of the five studies utilizing the NAC eye mark recorder to study visual performance/workload of Army pilots during helicopter operations will be published in future USAARL technical reports.

DISCUSSION

One of the usual techniques for determining visual performance/workload is to solicit opinions from aviators, asking them to describe those areas which they feel provide the necessary visual cues for safe helicopter flight. However, there is an extremely low correlation between aviator opinion and objective eye mark data when these two techniques are utilized simultaneously.[8,14] Indeed, it would seem that experienced aviators may be responding to cues which have become useful through experience and not necessarily those which they were taught and which they claim are those which provide them their best visual

information. Therefore, continued objective research data is required to isolate those visual cues critical for helicopter flight.

The methodology outlined in this work provides an effective means of measuring visual performance/workload through the corneal reflection technique. Utilizing the NAC Eye Mark Recorder, camera system, and the helicopter in-flight monitoring system (HIMS), data have been collected relating visual psychomotor and aircraft performance during multi-mission operations. The significance of this research resides in its potential to provide useful information about aviator sensory and motor performance in the rotary wing environment which may be applied to problems in current instrument panel designs and provide aids for innovative and efficient instrument displays for future rotary wing aircraft.

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